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Publication date:
1985

Document Version
Publisher's PDF, also known as Version of record

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Citation (APA):
Domanus, J. C. (1985). *Sensitometric Properties and Image Quality of Radiographic Film and Paper*. Risø National Laboratory. Risø-M No. 2500

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Sensitometric Properties and Image Quality of Radiographic Film and Paper

J. C. Domanus

SENSITOMETRIC PROPERTIES AND IMAGE QUALITY OF RADIOGRAPHIC FILM AND PAPER

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Paper accepted for presentation at the Eleventh World conference on Non-destructive Testing, Las Vegas, USA, November 3-8, 1985.

Abstract

When using X-ray film or radiographic paper for industrial applications one is interested in knowing not only their sensitometric properties (such as speed and contrast) but also the image quality obtainable with a particular brand of film or paper. Although standard methods for testing both properties separately are available it is desirable that the method permits the assessment of all the relevant properties together. The sensitometric properties are usually determined at constant kilovoltage and filtration at the X-ray tube, whereas radiographic image thicknesses. The use of the constant exposure technique could be used to compare both the sensitometric properties as well as the image quality for different

(Continued on next page)

*) Work performed under contract with Risø National Laboratory

radiographic materials. It consist of exposing different film or paper brands at a chosen, constant mAmin exposure when testing radiographic image quality for different thicknesses of a given material. From the results obtained with the constant exposure technique conclusions are drawn about its applicability as a standard method for assessing radiographic film and paper.

INIS desriptors: INDUSTRIAL RADIOGRAPHY; PAPER; PHOTOGRAPHIC FILM;
QUALITY CONTROL; SENSITIVITY; X-RAY RADIOGRAPHY

INDUSTRIAL : M1
QUALITY CONTROL : Q1, Q2
X-RAY RADIOGRAPHY : M2

ISBN 87-550-1100-4

ISSN 0418-6435

Grafisk Service Center, Risø 1985

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SENSITOMETRIC PROPERTIES AND IMAGE QUALITY OF RADIOGRAPHIC FILM AND PAPER

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1. INTRODUCTION

When using X-ray film or radiographic paper for industrial applications one is interested in knowing not only their sensitometric properties (such as speed and contrast) but also the image quality obtainable with a particular brand of film or paper.

Although standard methods for testing sensitometric properties and image quality separately are available, it is desirable to find a method by the use of which all the relevant properties could be tested together.

The sensitometric properties are usually determined at constant kilovoltage and filtration at the X-ray tube, whereas the radiographic image quality is tested at different kilovoltages and for different material thicknesses.

2. SENSITOMETRIC STANDARDS

In several countries standards have been published for the sensitometry of X-ray films used in medical and industrial radiography as well as dose monitoring. To those standards the ANSI standard for industrial [1] and medical [2] films as well as the German DIN standard [3] for medical film belong.

All those standards require the sensitometric testing to be performed by exposing the X-ray film to radiation of a well defined quality. The quality of the X-radiation is defined by the first half value layer (HVL) and initial filtration on the X-ray tube. The HVL method is commonly used to determine the effective energy of X-rays. Knowing the HVL one can calculate the attenuation coefficient of the monochromatic X-rays: $\mu = 0.693/d_{1/2}$. Then from adequate tables one can find the effective energy of the X-rays in keV.

A previous investigation in that field [4], presented at the 6th ICNT, has shown that the same effective energies (in keV) can be reached at different peak kilovoltages (kVp) of an X-ray machine and filtration at the X-ray tube. This is clearly illustrated on fig. 1. where exposure factors (kVp, filtration through Al or Cu, keV) are given for different X-ray machines used throughout the investigation [4]. This investigation has proved that it is not enough to specify the quality of X-rays by the effective energy only as e.g. the speed of X-ray films vary considerably for the same keV but different kVp.

According to ANSI [1] for the determination of the speed and average gradient (contrast) of industrial X-ray films, four radiation qualities are specified, as shown in table 1. For X-ray films characteristic curves ought to be produced in the nett density range from 0.2 to 4.0. From those curves the speed of the X-ray film is defined as the reciprocal of exposure, which produces the film density of 2.0.

The average gradient (contrast) is the slope of the straight line drawn on the density - log exposure curve between the points on the characteristic curve at nett densities of 1.5 and 3.5 for exposures with or without lead screens and 0.5 and 2.5 for exposures with fluorescent screens.

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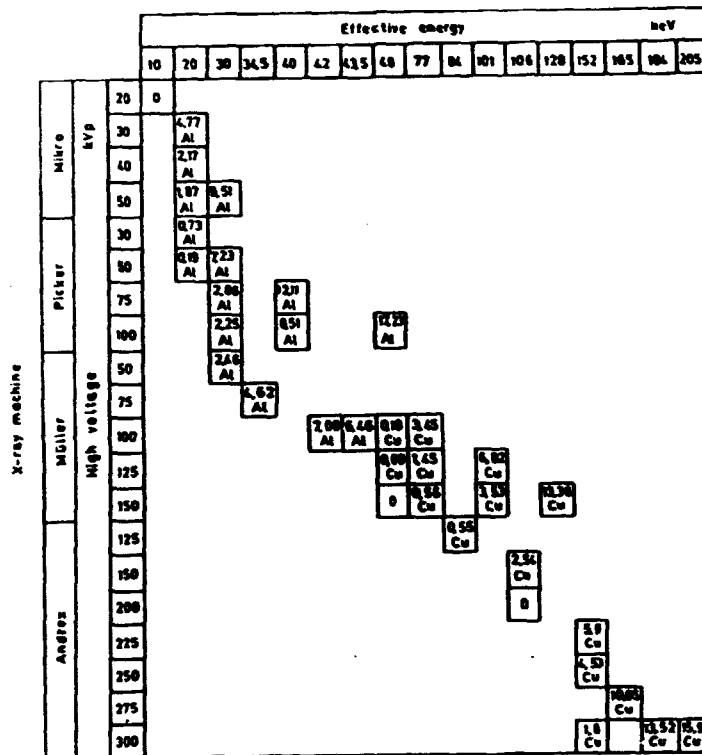


Fig. 1. Effective X-ray energy reached at different kVp and filtration

Table 1. Radiation quality according to ANSI

X-or gamma rays	Filter at source	HVL mm
100 kV	2.0 mm Cu	1.0 Cu
200 kV	8.0 mm Cu	3.5 Cu
Ir 192	8.0 mm Cu	-
Co 60	0	-

The ANSI method of determining speed and contrast of X-ray film from characteristic curves produced by radiation of the quality specified in table 1 is rarely used. The reason for that is, that it is rather difficult and cumbersome method to produce radiation of the specific quality mentioned above and therefore the user of the X-ray film will rarely use it. It could be, however, used by the X-ray film manufacturers, thus giving absolute and comparable data about film speed and contrast. Unfortunately, it is not done and although film manufacturers give relative speed and contrast of their different film brands they do not specify the radiation quality at which those data were obtained. In the numerous pamphlets, catalogues and handbooks on radiography, published

by X-ray film manufacturers, the standard ANSI method is not even mentioned. One can also wonder why in the NDT handbooks [5], when properties of X-ray films are described, no mention is given about standardized sensitometric procedures.

An even worse situation exists in the field of radiography on radiographic paper. Here no standards have been published and the problem is not treated in any publication, either from paper manufacturers nor in radiography handbooks. One must remember that the X-ray film and paper sensitivity depends strongly on the effective energy of X-rays. As was e.g. shown in [4], for almost all film brands the maximum film sensitivity occurred at about 45 keV and for other energies could be decreased as much as by a factor of 7.

Having in mind the existing situation in that field it was tried to find an easy and simple method for determining the sensitometric properties of X-ray film in everyday use of a particular radiographic laboratory. The results of this effort are described below.

3. IMAGE QUALITY STANDARDS

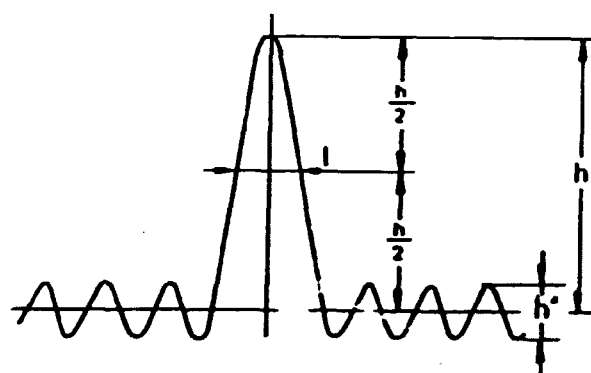
The situation is quite different in the field of radiographic image quality standards. Here one can find both international (ISO) standards [6] as well as many national ones (e.g. the ASTM standards [7,8]). One can also find ample information on that subject both in radiographic handbooks as well as in publications issued by X-ray film manufacturers.

The most widely used test pieces to control the quality of the radiographic image are the wire image quality indicators (IQI) [6,8] and the so called hole penetrameters [7]. The first are being most commonly used in Europe and the second in North America. The relative merits and drawbacks of use of the IQI's and penetrameters were discussed for many years. They were summarized e.g. in [9].

Both the wire IQI's as well as the hole penetrameters were used throughout the present investigation.

4. CONSTANT EXPOSURE TECHNIQUE

The constant exposure technique, described in 1976 by P.A. Ruault [10] was used in the assessment of the properties of the radiographic paper [11]. The principle of this technique was further explained in the following way [12]. From a densitometric scan of a defect (e.g.a hole) represented on a radiograph (see fig. 2) one can determine both the contrast and gradient of the radiographic signal and the quality of information obtained from a radiograph can be defined as the relation between the amplitude of the signal (h) and the noise (h').



h : signal amplitude
 h' : amplitude of background noise
 l : length of signal at half amplitude
 $C = \frac{h}{h'} = \text{contrast}$
 $G = \frac{h}{l} = \text{gradient}$

Fig. 2. Densitometric scan characterizing the radiographic signal

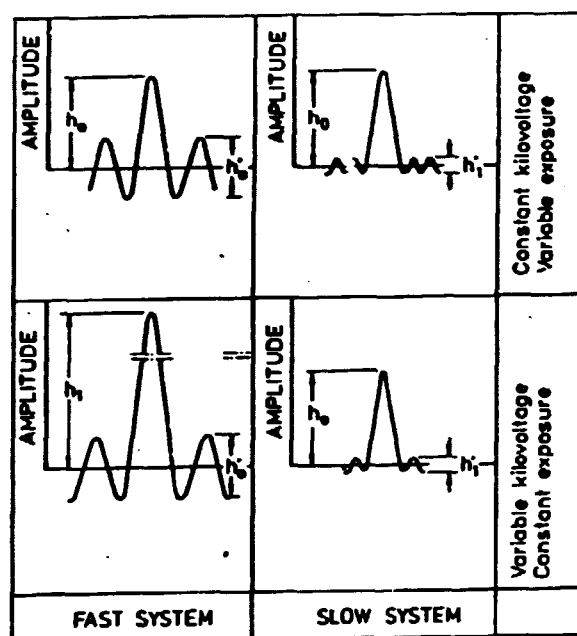


Fig. 3. Comparison between the constant kilovoltage and constant exposure technique

Looking on fig. 3, where ordinary technique (constant kilovoltage) used in radiography is compared with the constant exposure technique (for a fast and slow radiographic system) one can see that:

1) For the constant kilovoltage technique the signal from the defect has a constant amplitude, but the amplitude of the background noise depends on the speed of the system (it is lower for the slower system). Thus for the constant kilovoltage technique the quality of information obtained decreases with the increasing speed of the system.

2) If, on the other hand, one will maintain the same exposure for the faster system, then the kilovoltage can be lowered because a lower radiation dose is necessary for the faster system. The lowering of the kilovoltage increases the amplitude of the signal. Thus the ratio for the signal to background noise can be relatively improved for the faster system.

The constant exposure technique was successfully used at Risø to assess various radiographic systems (such as radiographic paper with fluorescent and fluorometallic screens [13], X-ray film and paper fast systems [14,15]) and was recently described in [16]. As a general conclusion one can say that by using the constant exposure technique the use of fast radiographic systems is possible and advisable as the loss of image quality is very small or nil. One can point out the main advantages of using fast radiographic systems as follows:

- Shorter exposure times due to the higher speed of the system.
- Lower material cost for paper radiography.
- Shorter processing times, especially with automatic processors.
- Lower labor costs due to shorter exposure and processing times.
- Lower equipment costs due to lower kilovoltages in use.
- Easier radiation protection due to lower kilovoltages in use.

5. EXPERIMENTAL PROCEDURE

In the situation described above, where no absolute data about sensitometric properties of X-ray film or paper can be found, it is necessary to produce those data in ones own radiographic laboratory for the exposure conditions and materials routinely radiographed.

Below, examples will be given how this was done at Risø for aluminium (30 mm thick) and steel (10 mm) plates exposed by self-rectified X-ray machines using different X-ray film and radiographic paper brands.

Those test plates were exposed together with the ISO wire IQI's and ASTM hole penetrameters both at constant kilovoltage (and varying exposure) as well as at constant exposure (and varying kilovoltage) to give the same film density of 2.5 or paper density of 1.0. From each radiograph the smallest percent ISO wire IQI diameter and the best ASTM percent penetrometer level were determined by three observers.

The slowest X-ray film (Kodak Industrex single coated SR) was chosen as reference with a relative speed of 1.0. For this film to reach the density of 2.5 for 30 mm Al an exposure of 25 mAmin at 170 kV and for 10 mm Fe an exposure of 100 mAmin at 215 kV were necessary (at 1 m FFD).

Altogether 12 Kodak Industrex and 10 Agfa-Gevaert Structurix film, paper and screen combinations were tested (FM means fluorometallic screens).

6. RELATIVE SPEED AND REDUCTION IN KILOVOLTAGE

The results of the investigation described above are given in fig. 4. Here on the upper part results obtained for Kodak Industrex systems are represented whereas on the lower part results for Agfa-Gevaert Structurix systems are given. For the constant kilovoltage (170 kV for 30 mm Al and 215 kV for 10 mm Fe) exposures (in mAmin) necessary to obtain densities of 2.5 or 1.0 are shown on the vertical scale in fig. 4. By dividing the exposure (25 mAmin for 30 mm Al and 100 mAmin for 10 mm Fe) necessary for the slowest system (Kodak single coated Industrex SR film) by the exposure necessary for other systems one can calculate the relative speed of the system (shown in the tables in fig. 4.).

On the other hand, for the constant exposure (25 mAmin for 30 mm Al and 100 mAmin for 10 mm Fe) kilovoltages necessary to obtain respectively densities of 2.5 and 1.0 are shown on the horizontal scale in fig. 4. In the tables given in this figure absolute and relative kilovoltage reductions are given, possible when using faster systems (than Kodak SR) with the constant exposure technique.

As can be seen the relative speed factor can be as high as 625 and relative reduction in kilovoltage - 36%.

7. CONTRAST

Unlike the speed, the contrast of X-ray film and paper does not depend much on radiation quality. Therefore one can calculate X-ray film contrast from characteristic curves given by film manufactureres. While calculating contrast of X-ray film the criteria given in the ANSI standard [1] can be used (as quoted in 2 above).

Very often the contrast of the X-ray film is given together with the characteristic curve by the X-ray film manufacturer.

Unfortunately, there are no sensitometric standards for the radiographic paper. As is well known the paper density does not increase in such a way as that of the X-ray film (while exposure is increased) and reaches a saturation level. Therefore for the radiographic paper not the average gradient (contrast) is calculated but the maximum

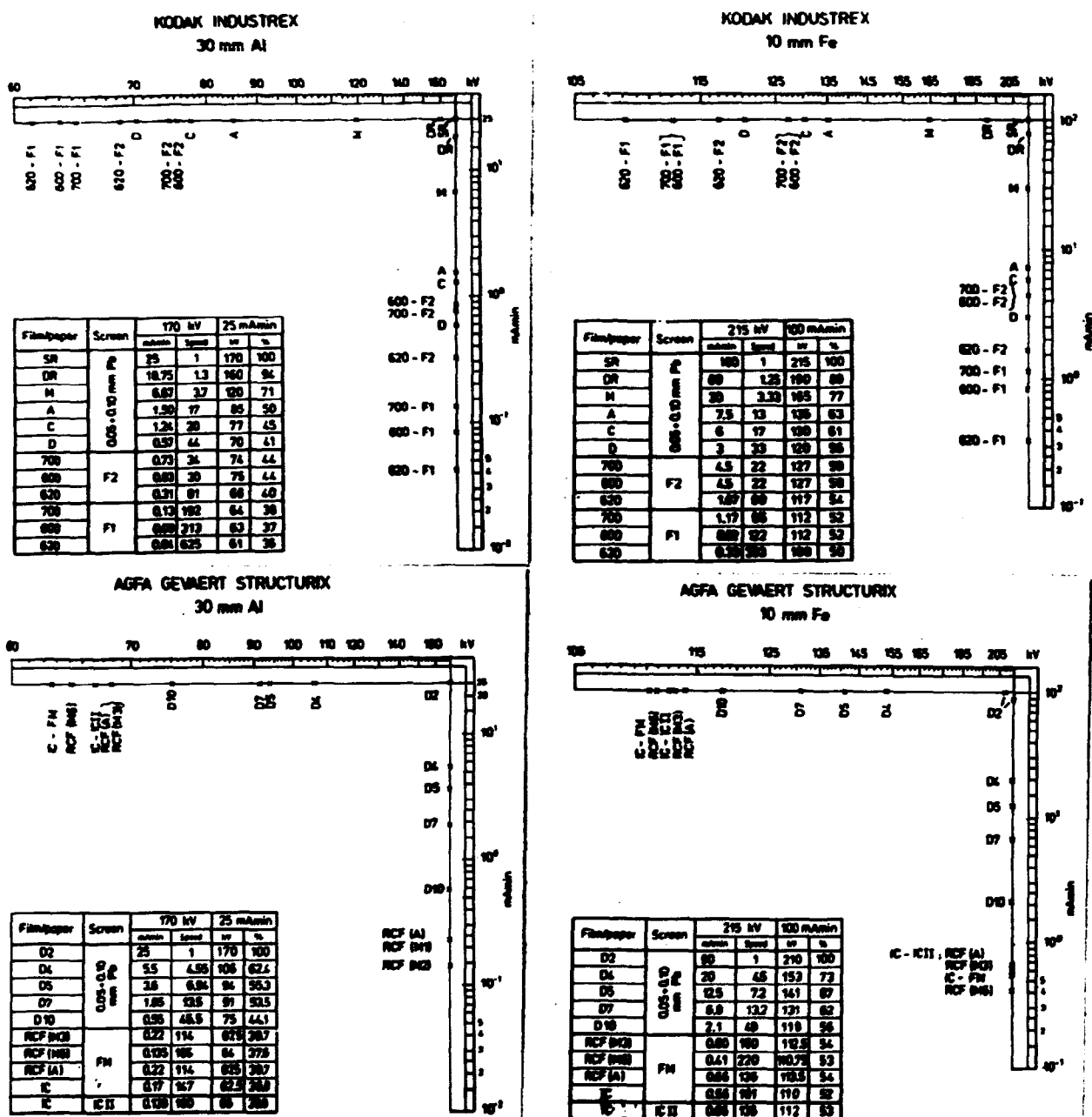


Fig. 4. Constant exposure and constant kilovoltage exposures for Kodak Industrex and Agfa-Gevaert Structurix systems

gradient (calculated from the characteristic curve). The relation between the radiographic paper contrast and its optical reflection density was studied previously [17] and it was proved that the maximum contrast occurs at the paper density of about 1.0 (see also [18]).

8. RADIOGRAPHIC IMAGE QUALITY

As explained in 5 above the radiographic image quality was tested by the use of 30 mm Al and 10 mm Fe plates on which ISO wire IQI's and ASTM hole penetrameters were placed. Thus all combinations of X-ray film and radiographic paper and intensifying screens were tested using both the constant kilovoltage as well as the constant exposure technique. The results of this investigation are shown on fig. 5 for Kodak, and on fig. 6 for Agfa-Gevaert systems obtained by the constant exposure technique.

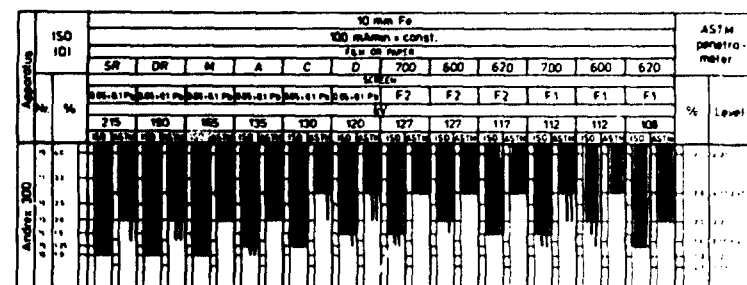


Fig. 5. Percent radiographic quality for Kodak systems obtained by the constant exposure technique

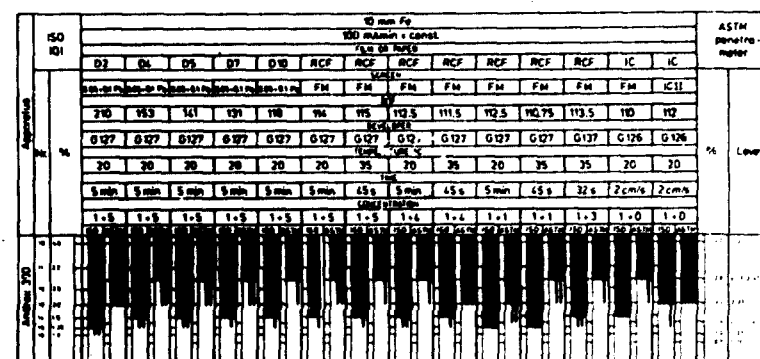


Fig. 6. Percent radiographic quality for Agfa-Gevaert syhstems obtained by the constant exposure technique

1) As was demonstrated above relative speed of a certain film or radiographic paper and intensifying screens combination can easily be determined together with radiographic image quality without recurring to special exposure and dosimetric technique, as required by the sensitometric standards. No half-value layer measurements are necessary and no characteristic curves are needed. The only special instrument needed is a transmission (for film) or reflection (for paper) densitometer. The determination of

9. CONCLUSIONS

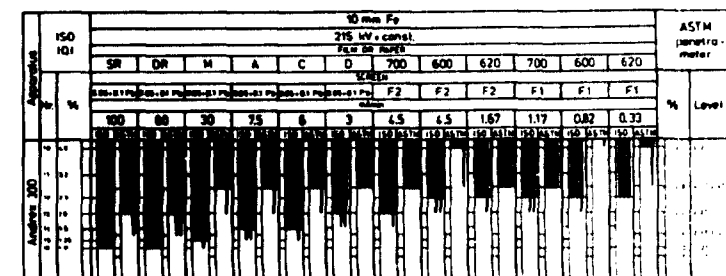
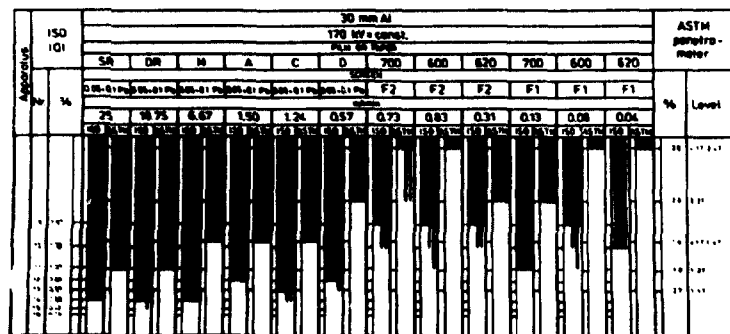


Fig. 7. Percent radiographic quality for Kodak systems obtained by the constant kilovoltage technique

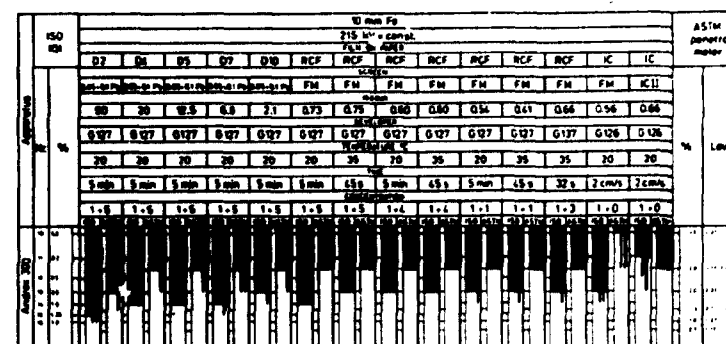
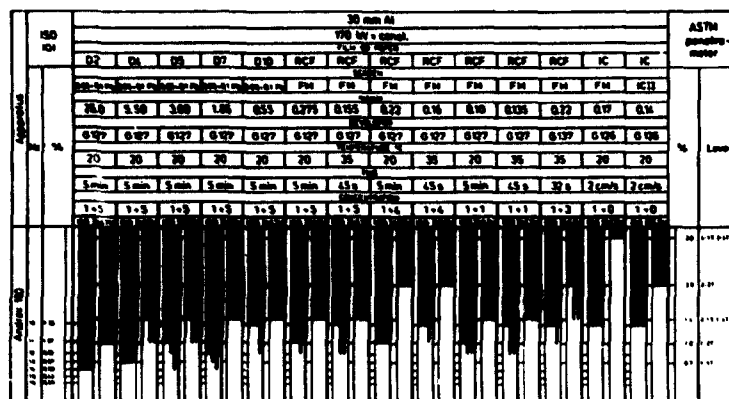


Fig. 8. Percent radiographic quality for Agfa-Gevaert systems obtained by the constant kilovoltage technique

relative speed and image quality can in general only be done for those materials and their thicknesses which are generally used in a particular radiographic laboratory.

2) The contrast of the X-ray film or radiographic paper can easily be determined from characteristic curves published by film and paper manufacturers.

3) By using the constant exposure technique one can easily find faster radiographic system and at the same time have the information wheather the radiographic image quality of this system satisfies the particular quality requirements.

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Date

September 1985

Department or group

Metallurgy

Group's own registration
number(s)

8 pages + 1 tables + 8 illustrations

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When using X-ray film or radiographic paper for industrial applications one is interested in knowing not only their sensitometric properties (such as speed and contrast) but also the image quality obtainable with a particular brand of film or paper. Although standard methods for testing both properties separately are available it is desirable that the method permits the assessment of all the relevant properties together. The sensitometric properties are usually determined at constant kilovoltage and filtration at the X-ray tube, whereas radiographic image quality is tested at different kilovoltages and for different material thicknesses. The use of the constant exposure technique could be used to compare both the sensitometric properties as well as the image quality for different radiographic materials. It consists of exposing different film or paper brands at a choosen, constant mAmin exposure when testing radiographic image quality for different thicknesses of a given material. From the results obtained with the constant exposure technique conclusions are drawn about its applicability as a standard method for assessing radiographic film and paper.

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